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# LABORATORY INVESTIGATION OF ICING IN THE CARBURETOR AND SUPERCHARGER INLET ELBOW OF AN AIRCRAFT ENGINE

# IV - EFFECT OF THROTTLE DESIGN AND METHOD OF THROTTLE OPERATION ON INDUCTION-SYSTEM ICING CHARACTERISTICS

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NACA

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NACA AIRCRAFT ENGINE RESEARCH LABORATORY

MEMORANDUM REPORT

for the

Air Technical Service Command, Army Air Forces

# LABORATORY INVESTIGATION OF ICING IN THE CARBURETOR AND SUPERCHARGER INLET ELBOW OF AN AIRCRAFT ENGINE

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## SUMMARY

In order to eliminate the formation of ice on the carburetor throttle plates of an aircraft-engine induction system, two modifications of the throttle design and a variation in the method of throttle operation of the twin-barrel injection carburetor were tested.

The effect of each modification was investigated under severe icing conditions at simulated engine conditions of normal rated power, maximum cruising power, and 60-percent normal rated power. Reversal of the throttle plates augmented the formation of ice. Electrically heated throttle plates were maintained free of ice under severe icing conditions by the application of 350 to 900 watts of power to each plate. The operation of the throttles by the automatic manifold-pressure regulator did not prevent the formation of ice but it did prevent the immediate drop in air flow usually caused by icing.

Limiting-icing conditions were established for operation using electrically heated throttle plates but the results of the tests made on the other modification did not warrant the establishment of limiting-icing curves.

## INTRODUCTION

As part of a general investigation requested by the Air Technical Service Command, Army Air Forces, of ice formation and elimination in the induction system of a fighter airplane, tests were made to determine the effect of different throttle designs and method of throttle operation on induction-system icing characteristics. During previous laboratory icing tests of this twin-barrel injection carburetor on an engine-stage supercharger assembly, a characteristic ice accretion occurred on the edges and under sides of the carburetor throttle plates. (See reference 1.) The ice formations were caused by pseudoadiabatic expansion of the air stream through the carburetor venturis and past the throttle edges and from refrigeration caused by the evaporation of fuel, which eddied upstream to cool the under side of the throttle plates.

In order to eliminate some of the icing that occurred in the induction system, two throttle designs and a variation in the method of operating the throttles to maintain air flow were tested at the NACA Cleveland laboratory during the fall of 1944. The designs included a throttle that opened toward the front instead of toward the rear as in the conventional installation for this induction system and a set of electrically heated throttle plates. The variation in operational method consisted in using an automatic manifold-pressure regulator to operate the throttle during icing conditions. In work done by the British Royal Aircraft Establishment reported in reference 2, oil-heated throttle plates were used for prevention of carburetor icing.

The range of conditions for which these modifications were tested include runs made at simulated normal rated power, maximum cruising power, and 60-percent rated power. The investigation includes runs made under severe-icing conditions for all the simulated powers.

## APPARATUS

The induction system investigated in these tests consisted of a twin-barrel injection carburetor mounted on an engine-stage supercharger assembly. The supercharger impeller was driven by a dynamometer and induced the air flow through the carburetor. The desired conditions of temperature, pressure, and humidity were controlled in the air stream in the ducting upstream of the carburetor (reference 3). Tests were made with two types of modified throttle and an automatic manifold-pressure regulator.

Reversed-opening throttle plates. - The conventional throttle operation was so arranged that the trailing edge of the throttle plate met the rear wall of the carburetor body in the closed position. In opening, the plates were rotated clockwise as seen from the left side of the carburetor. The conventional throttle plates were reversed in such a manner that the trailing edge of the plates met the front wall of the carburetor body when in the closed position and opened by rotating counter clockwise, as seen from the left side of the carburetor.

Heated throttle plates. - For the tests of the heated throttle plates, the conventional throttle butterfly valves were replaced by plates about one-sixteenth inch thicker than the conventional butterfly valves, each containing a 1000-watt heating element. The power input was controlled by a variable transformer and measured by means of a wattmeter, a voltmeter, and an ammeter. A thermocouple was embedded in the surface of each plate one-third of the distance from the trailing edge. A comparison of the heated throttle-plate assembly with the conventional throttle-plate assembly is shown in figure 1.

Automatic manifold-pressure regulator. - The automatic pressure regulator type AAF-A2 is designed to maintain a selected manifold pressure by regulating the carburetor throttle opening.

## TEST PROCEDURE

The test procedure used in these tests was similar to that established for the icing tests described in reference 3. In general, this procedure involved the stabilization of the air-stream conditions of flow, humidity, temperature, and pressure. The apparatus was operated under the simulated engine power conditions presented in table I for the 15-minute test period and readings of fuel flow, air flow, and air pressures were made at timed intervals.

A variation of this procedure was required for the heated throttle plates. During the tests with the heated throttle plates, the power was supplied to the plate before icing conditions were established and the temperature of the plate was maintained between 150° and 33° F. In one test, heat was supplied to only one of the throttle plates.

When the manifold-pressure regulator was used, a similar procedure was followed except that the tests were permitted to continue for periods of time varying from 15 minutes to $2\frac{1}{4}$ hours. The manifold-pressure regulator could not be used in the tests that were run at a simulated engine condition of 60-percent normal rated power because the supercharger back pressure was too low. In these tests, the operation of the manifold-pressure regulator was simulated by manually maintaining the back pressure at a constant value throughout the test.

## RESULTS AND DISCUSSION

Reversed-opening throttle design. - Reversing the throttle plates caused serious icing at temperatures and moisture contents above those at which icing occurred with conventional throttle installation (fig. 2).

Electrically heated throttle plates. - The effect of heated throttle plates on the icing characteristics of an aircraft-engine induction system at 60-percent rated power is shown in figure 3. The dashed line is the upper limit for conditions of carburetor-air temperature and humidity at which serious-icing conditions form. Use of the heated plates reduced the serious-icing range to the limit indicated by the solid line.

In order to determine these limiting conditions, an input of 400 to 500 watts to each throttle plate was used for carburetor-air temperatures of 29.5° to 50° F and for humidities up to saturation. Power input to the heating elements was increased with the rate of free-water injection and varied from 500 to 900 watts for water-injection rates of 100 to 1000 grams per minute. The effect of a change in power input on air-flow reduction between heated and unheated throttle plates is shown in figure 4.

In two of the runs, small formations of ice on the tips of the throttle plates were noted. Such formations can be observed on the under side of the throttle plates in figure 5. Light frost was found on the upper side of the throttle plates at the center of the carburetor in two runs. For other than these formations, ice-free throttle plates were maintained during all runs.

The ice formation in the supercharger inlet elbow in figure 5 is typical of the type that developed with the heated plates. Ice also accumulated in the space between the bottom of the carburetor and the top of the supercharger-inlet-elbow rib and extended outward into the air stream. At the low throttle openings in several instances, the air flow was considerably reduced by ice accretions, which had built up in the front part of the carburetor throttle barrels, although the throttle plates remained free of ice. An ice formation that resulted when the left plate was unheated and the right plate heated is shown in figure 6. With the heated throttle plate maintaining an opening in the right throttle barrel, it was possible to ice the left throttle barrel until it was completely filled with ice. A small ice formation can be seen on the unheated throttle plate in figure 6.

The heated throttle plates did not alter the icing characteristics of the system at the rated-power conditions because the wider throttle opening tended to keep the throttle plates free of ice and to form restricting ice in the supercharger inlet elbow. Several runs made under serious-icing conditions showed no appreciable change in the icing characteristics at this simulated engine power.

Automatic manifold-pressure regulator. - The operation of the automatic manifold-pressure regulator did not prevent the formation of serious icing. The operation did, however, retard the 2-percent drop in air flow for longer than the usual 15-minute period of operation. As the icing progressed, the throttles frequently became frozen and the air flow dropped as the ice continued to build up. Typical runs made with the manifold-pressure regulator controlling the throttles are compared with test runs made under similar icing conditions but with fixed throttle (fig. 7). The automatic manifold-pressure regulator may produce a dangerous ice condition because it delays the appearance of icing symptoms until a large formation has built up.

## SUMMARY OF RESULTS

From laboratory tests conducted to determine the effect of different throttle designs and a method of throttle operation, the following results were obtained, which are applicable only to the modifications in throttle design and operation when incorporated in a twin-barrel injection carburetor mounted on an engine-stage supercharger assembly.

1. Reversal of the throttle plates in order to point the trailing edges of the throttles toward the front of the air passage produced more severe icing than the conventional throttle arrangement.

2. Ice was eliminated from the throttles under some of the most severe icing conditions by the application of 350 to 900 watts of power to each plate.

3. The carburetor-engine combination allowed the formation of ice on the carburetor and accessory-housing air-passage walls even when the throttles were kept free of ice by heat. The carburetor and air-passage walls would require the application of heat for more complete protection against serious icing.

4. The operation of the carburetor throttles by the automatic manifold-pressure regulator did not prevent the formation of ice but did prevent the immediate drop in air flow usually caused by icing.

5. The automatic manifold-pressure regulator could not be regarded as an ice-protection means because, when icing proceeded to the point at which manifold pressure and air flow were affected, the throttles were frozen in position and the engine performance was adversely affected.

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National Advisory Committee for Aeronautics,
Cleveland, Ohio.

REFERENCES

1. Essex, Henry A., Keith, Wayne C., and Mulholland, Donald R.: Laboratory Investigation of Icing in the Carburetor and Supercharger Inlet Elbow of an Aircraft Engine. II - Determination of the Limiting-Icing Conditions. NACA MR No. E5L18a, 1945.

2. Clothier, W. C.: Ice Formation in Carburetors. R.A.S. Jour., vol. XXXIX, no. 297, Sept. 1935, pp. 761-800; discussion, pp. 800-806.

3. Mulholland, Donald R., Rollin, Vern G., and Galvin, Herman B.: Laboratory Investigation of Icing in the Carburetor and Supercharger Inlet Elbow of an Aircraft Engine. I - Description of Setup and Testing Technique. NACA MR No. E5L13, 1945.

TABLE I - SUMMARY OF TEST CONDITIONS USED IN LABORATORY INVESTIGATION OF

ICING CHARACTERISTICS OF AIRCRAFT-ENGINE INDUCTION SYSTEM

| Power | Engine speed (rpm) | Fuel octane number | Fuel temperature (°F) | Fuel-air ratio (approximate) | Free-water temperature (°F) | Approximate carburetor top-deck pressure (in. Hg absolute) | Approximate supercharger-outlet pressure (in. Hg absolute) | Approximate air flow (lb/hr) |
|---|---|---|---|---|---|---|---|---|
| Normal rated | 2600 | 62 | 40 | 0.095 | 40 | 27.80 | 43.5 | 7700 |
| Maximum cruising | 2300 | 62 | 40 | 0.080 | 40 | 27.80 | 35.0 | 5775 |
| 60-percent normal rated | 2200 | 62 | 40 | 0.080 | 40 | 27.80 | 30.5 | 4620 |

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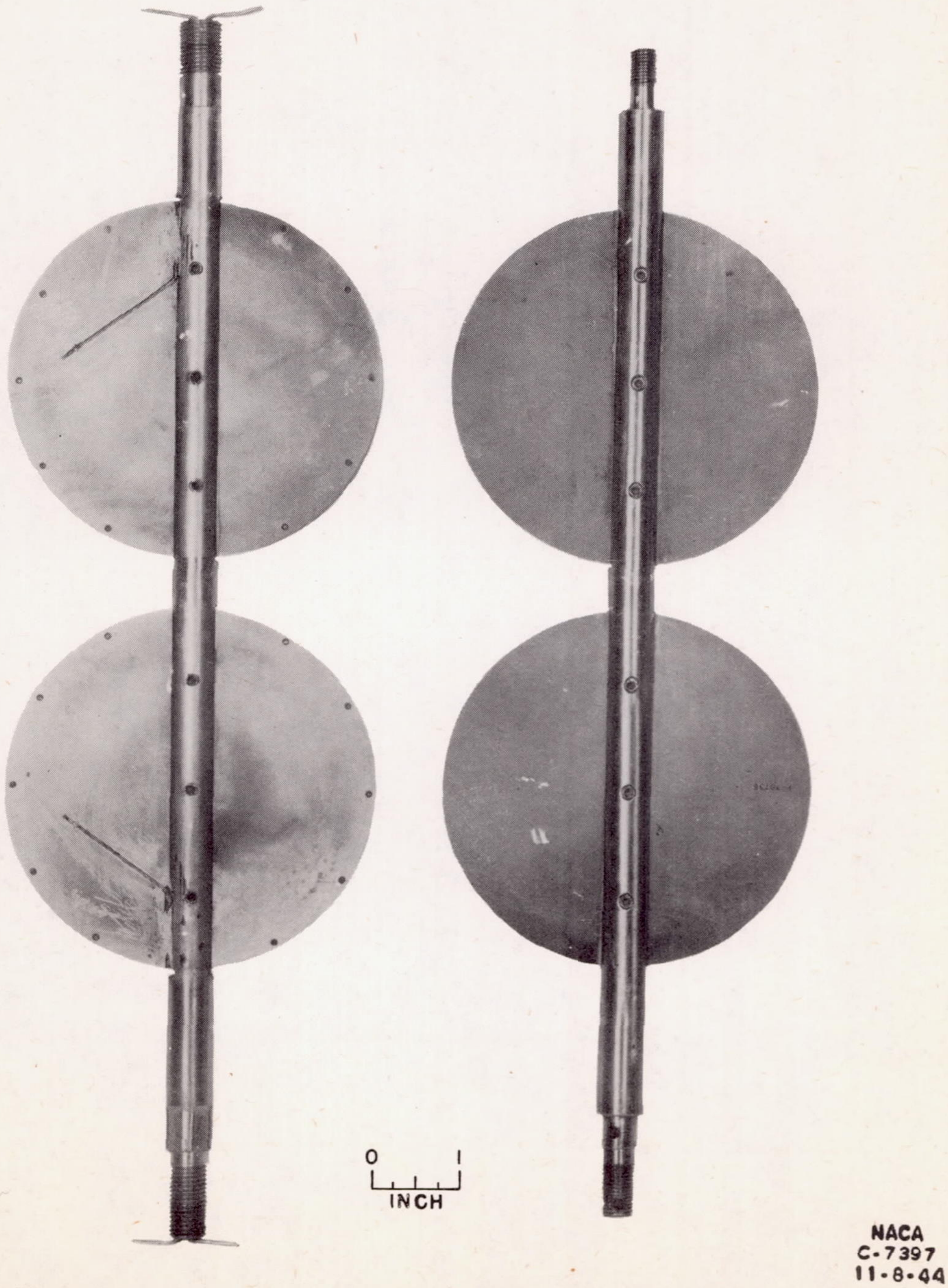



(a) Modified heated throttle plate and hollow shaft.

(b) Conventional throttle plate and shaft.

Figure 1. - Comparison of heated throttle plates and conventional throttle plates.

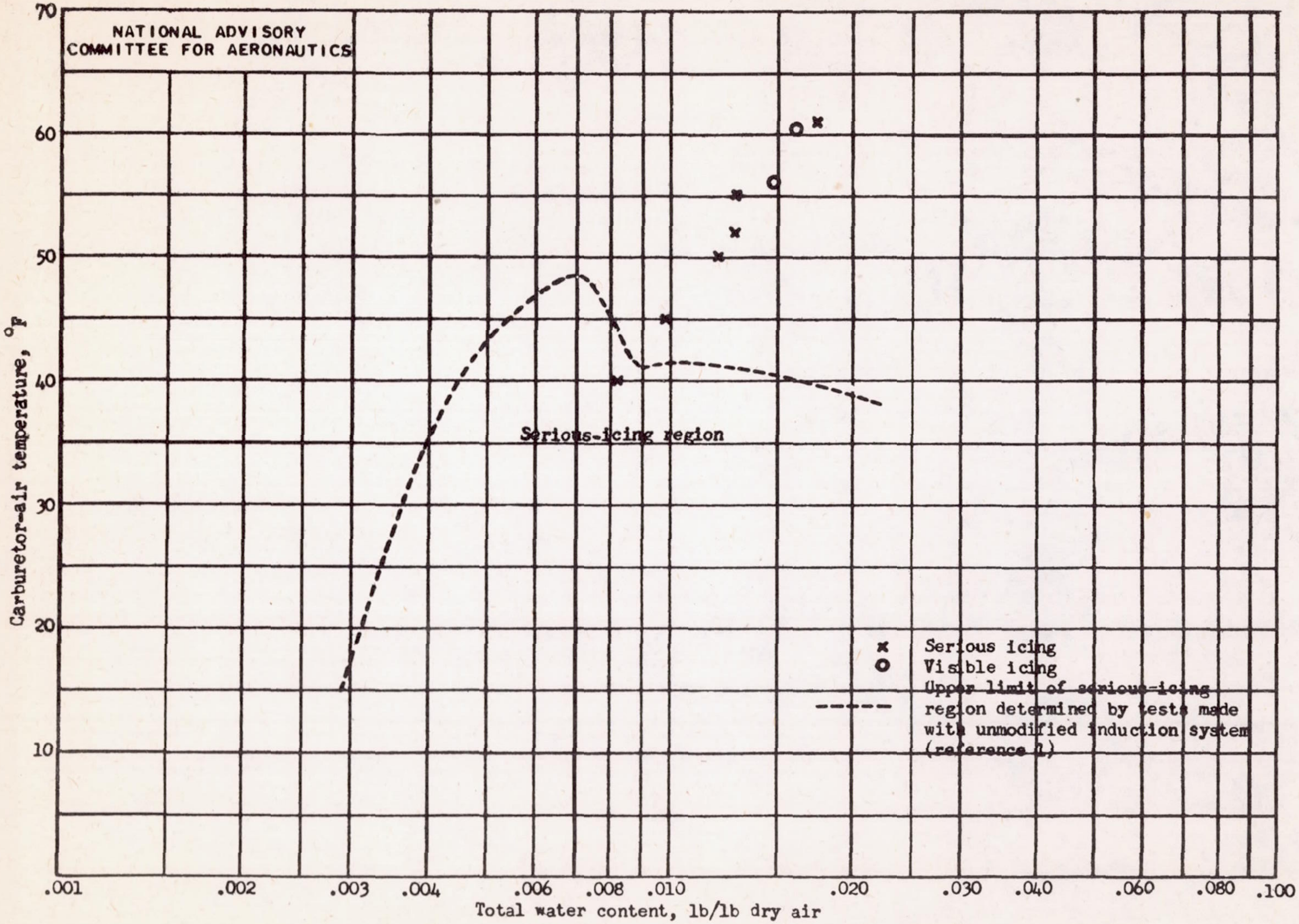



Figure 2. - Effect of reverse-opening throttle design on limiting-icing conditions at 60-percent rated power.

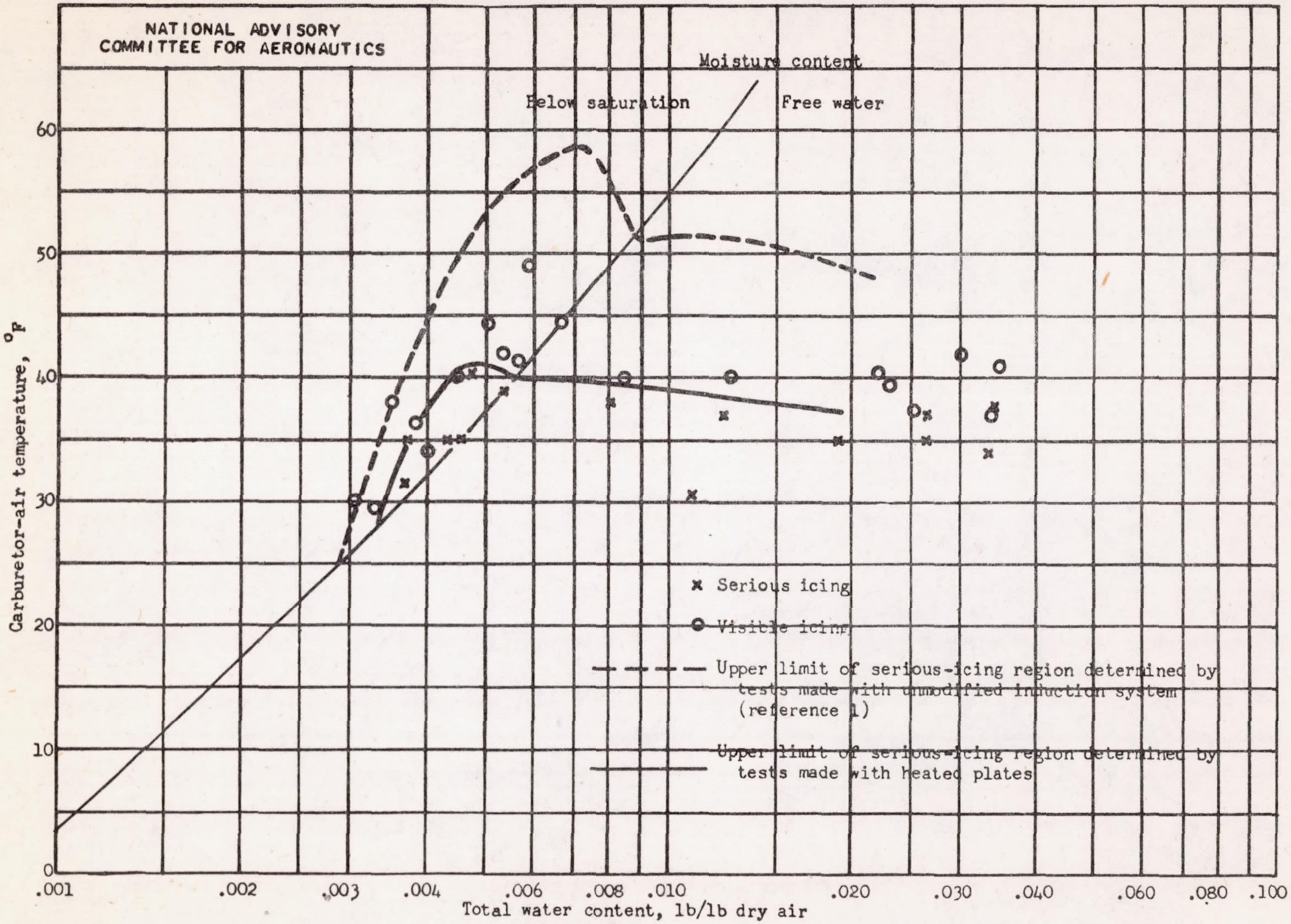
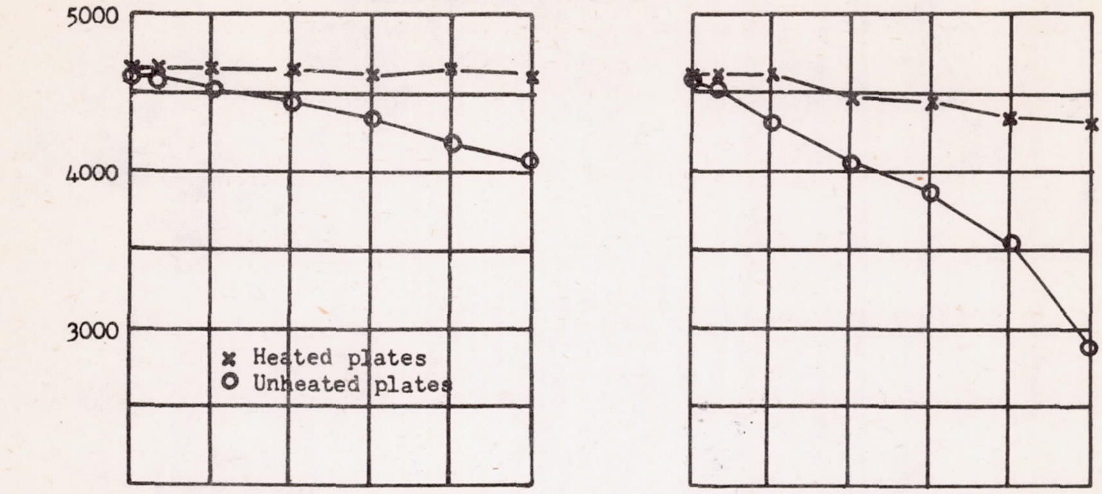



Figure 3. - Effect of heated throttle plates on limiting-icing conditions of carburetor-air temperature and water content at simulated 60-percent rated power.




(a) Relative humidity, 81 percent; water injection, 0 grams per minute; average watts per plate, 425.

(b) Relative humidity, 100 percent; water injection, 0 grams per minute; average watts per plate, 450.

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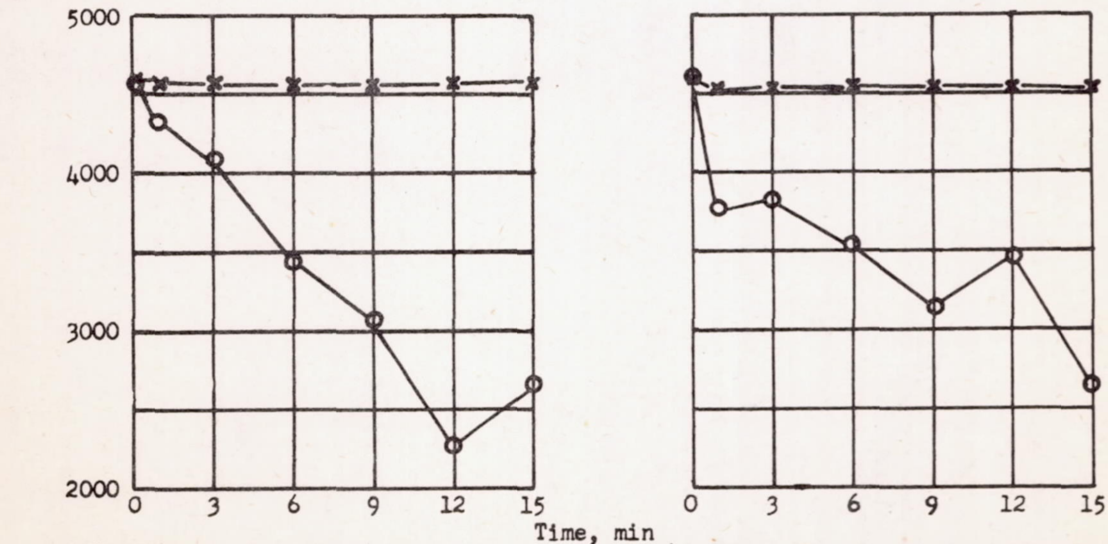


(c) Relative humidity, 100 percent; water injection, 100 grams per minute; average watts per plate, 790.

(d) Relative humidity, 100 percent; water injection, 1000 grams per minute; average watts per plate, 860.

Figure 4. - Comparison of air flow with time for icing tests made with heated and unheated throttle plates at 60-percent rated power. Initial conditions: air flow, 4620 pounds per hour; fuel-air ratio, 0.080; carburetor-air temperature, 40° F.

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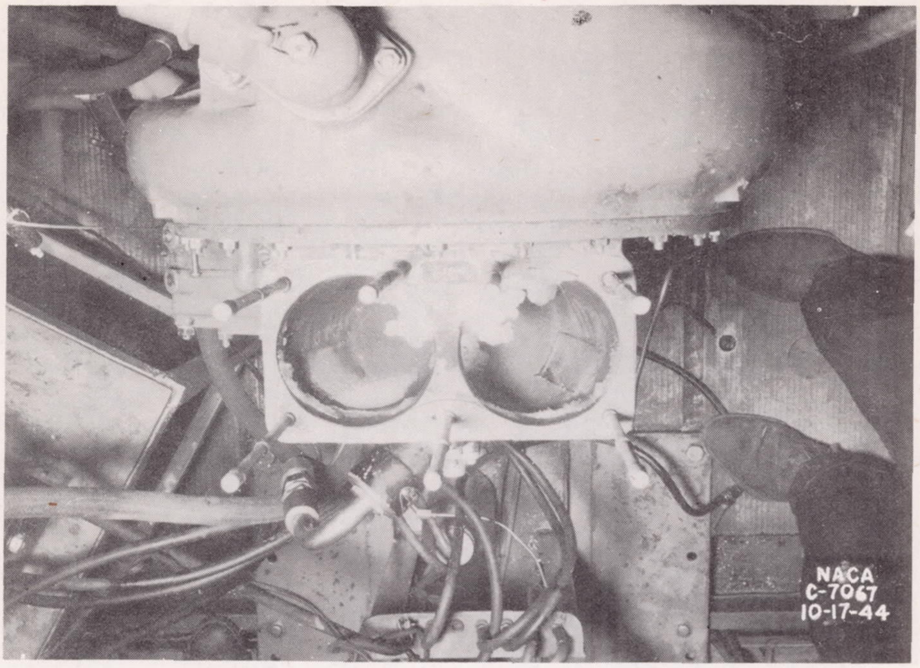
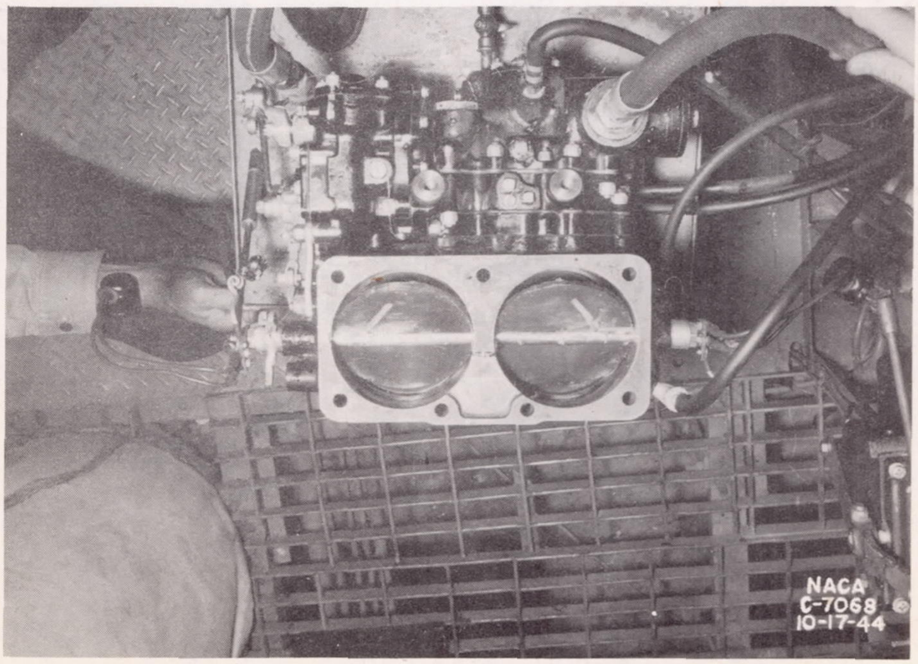



(a) Ice formation in supercharger inlet elbow.




(b) Ice formation on throttle-plate edges.

Figure 5. - Serious icing with heated throttle plates. Carburetor-air temperature, 35° F; relative humidity, 100 percent; initial air flow, 4670 pounds per hour; fuel-air ratio, 0.080; minimum air flow after 15 minutes, 4535 pounds per hour; power input per plate, 500 watts.

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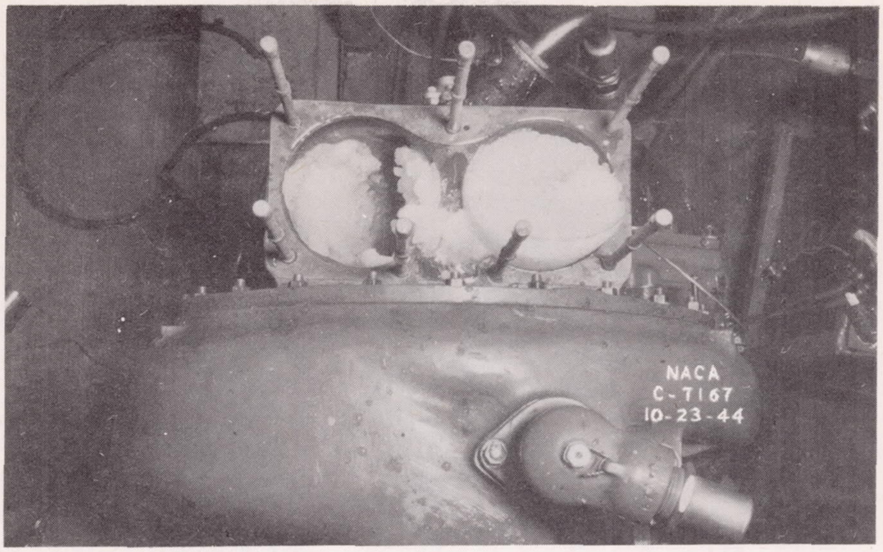
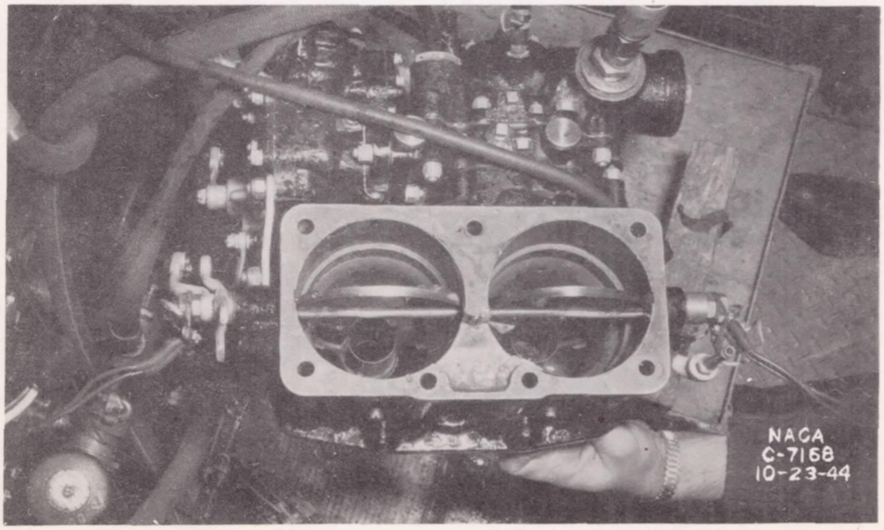
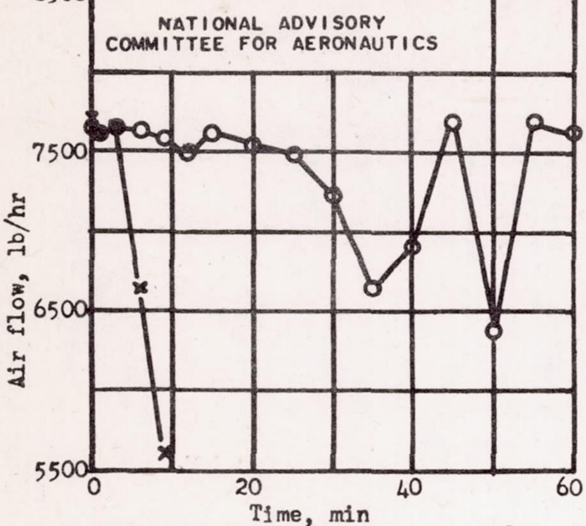



(a) Supercharger inlet elbow with ice completely blocking left inlet; right inlet under heated throttle plate open to passage of air.

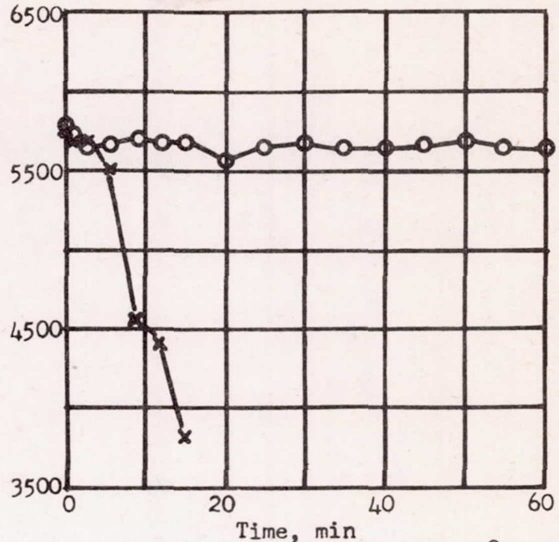



(b) Carburetor bottom view with ice adhering to tip of left unheated plate.

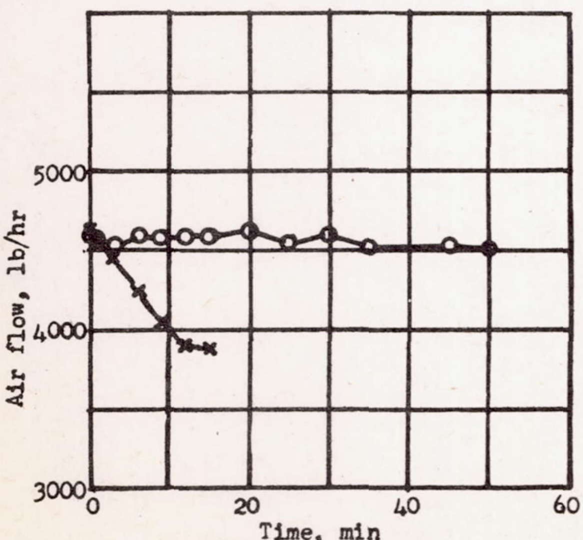
Figure 6. - Serious icing with left throttle plate unheated and right throttle plate heated. Carburetor-air temperature, 34° F; relative humidity, 100 percent; initial air flow, 4670 pounds per hour; fuel-air ratio, 0.080; minimum air flow after 3 minutes, 2000 pounds per hour; power input to right plate, 600 watts; power input to left plate, 0 watt; water injection, 600 grams per minute.




(a) Carburetor-air temperature, 32° F; relative humidity, 100 percent; engine speed, 2600 rpm; fuel-air ratio, 0.095.




(b) Carburetor-air temperature, 40° F; relative humidity, 100 percent; water injection, 100 grams per minute; engine speed, 2300 rpm; fuel-air ratio, 0.080.




(c) Carburetor-air temperature, 40° F; relative humidity, 90 percent; engine speed, 2200 rpm; fuel-air ratio, 0.080.

o Manifold-pressure-regulator water injection, 500 gram/min

x Fixed-throttle water injection, 625 gram/min

Figure 7. - Comparison of effect on air flow of manifold-pressure-regulator operation with fixed throttle operation under severe-icing conditions.